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Evacuees' behaviors of using elevators during evacuation based on experiments

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Abstract

In this paper, experiments are carried out to study how evacuees behave and what factors influence their behaviors during evacuation. Two key factors, which may influence evacuees' behaviors, are tested in our experiments: number of waiting evacuees, and smoke. Furthermore, the shapes of queuing, such as arch and line, will influence the time of evacuees going through elevator doors. Several interesting phenomena are also observed in our experiments. Finally, several suggestions, such as the width of doors and the design of elevator lobbies, are given to building designers on the issues mentioned above.

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Keywords: elevator evacuation; experiments; human behaviors.

1. Introduction

Evacuation elevators are now allowed to be used for high-rise building evacuation in several countries according to their building codes, such as the UK, Australia, Malaysia, China and USA (ICC (2009), NFPA101 (2009), NFPA5000 (2009), British Standards Institute (2008), CIBSE (2000), Australian Building Codes Board (2008)). To use these evacuation elevators effectively, many issues, such as scheduling, control, lobby design, and car design, should to be re-examined, and evacuees' behaviors, should also be understood (Kinsey (2011), Heyes (2009a)). Take elevator scheduling for example, the load time during evacuation is generally different from that under normal conditions because evacuees do not want to get out when a car is overload. Such overcrowding is crucial since it

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will lead to the failure of evacuation elevators. All these issues are relative to human behaviors (Kinsey, et al. 2010). However, there are few studies discussed these behaviors since nearly no elevator evacuation events or experiments are recorded. As a result, how evacuees behave when using evacuation elevators and what features will influence their behaviors are important.

There are also many features, such as emergency environment, number of waiting evacuees, familiarity, education and training, and floor level, which may influence human behaviors during elevator evacuation (Heyes, et al. (2009a), Heyes, et al. (2009b), Kinsey, et al. (2009), Lee, et al. (2004), Ronchi, et al. (2013)). As we want to study evacuees' behaviors when they use elevators, two of these features will be tested: emergency environment and number of waiting evacuees. The emergency environment includes fire and smoke (Chow, et al. (1998)), but fire cannot be tested in experiments. As a result, harmless smoke is picked up in our experiments. When evacuees move in smoke conditions (Jeon, et al. (2005)), most of them will become nervous and nervous will influence how they behave (Kobes, et al. (2010)). The number of waiting evacuees will determine whether the phenomenon of overcrowding happens. For example, the capacity of most elevators is 13 persons. If the number of waiting evacuees is 10, the car will not overload. But if the number of waiting evacuation is 15, the car must overload. Relevant references will be reviewed in Section 2.

In this paper, experiments are carried out to study how evacuees behave and what factors influence their behaviors during evacuation. Elevators used in the experiments are all customer elevators, and they were tested to be safe enough for our experiments. All the participants are students from Tsinghua University, and they are told that elevators are their first choice to evacuate. To enhance their motivations, participants are told to use stairs on the tenth floor where they are waiting for elevators as "punishment" if they cannot use elevators. Totally 30 participants are divided into two groups, and each group took part in 16 experiments. As a result, 32 experiments are carried out, and the experiment plans and procedure will be presented in Section 3.

The results of the experiments and data analysis will be discussed in Section 4. We find that the number of evacuees will influence evacuees' behaviors, but the smoke will not. When the number of waiting evacuees is larger than the capacity of a car, the time to open and close elevator doors is long. Furthermore, the shapes of queuing, such as arch and line, will influence the time of evacuees going through elevator doors. The evacuees with the shape of arch went faster than those with the shape of line. Several interesting phenomena are observed in our experiments, such as leader and follower, jam, and social bond. Finally, several suggestions, such as the width of doors and the design of elevator lobbies, are given to building designers on the issues mentioned above.

2. Literature Review

This section reviews relevant literature on elevator evacuation, which including building codes and the use of elevators in past fire events (sub-section 2.1), and features that affecting human behaviors (sub-section 2.2).

2.1. Elevator Evacuation

In most of the high-rise buildings around the world, elevators are not allowed to be used during evacuation (Bukowski (2008)). People are also educated or trained not to use elevators when a building is on fire. However, occupants in high-rises or ultra-high-rise buildings need a long period of time to go downstairs, and people with disabilities even cannot use stairs during evacuation (Proulx, et al. (2009)). For example, the event of WTC 9/11 (Groner (2002)) highlighted the difficulties in evacuating people on all floors simultaneously, and it took a long time to evacuate all the evacuees by using stairs along. It is believed that evacuation elevators can be used to accelerate building evacuation process according to several evacuation events (Averill, et al. (2005), Howkins (2000), Proulx, et al. (2004), Proulx, et al. (1995), Sekizawa, et al. (1999)). As a result, several countries consider using evacuation elevators in high-rise building according to their building codes (ICC 2009, NFPA101 2009, NFPA5000 2009, British Standards Institute 2008, CIBSE 2000, Australian Building Codes Board 2008).

There are also several problems that concerning the use of evacuation elevators. The proportion of evacuees using elevators or stairs has always been concerned as the most important problem about the combination use of elevators and stairs (Kinsey (2011), Heyes (2009a), Groner, et al. (1992)). To the evacuees who want to use elevators, how long will they wait and under what conditions they will wait are also important (Kinsey (2011),

Heyes (2009a)). For safety aspects, flame, heat and smoke may invade the elevator shaft (Barker (1995)). Moreover, when elevator cars move, negative pressure will suck smoke inside the elevator, which is named as the piston effect (Chien et al. (2011), Klote (1983)). The power supply and water protection are also required on higher levels (Bukowski (2005), Bukowski (2010a), Bukowski (2010b)). The pick-up locations are also different from normal elevator lobbies, and these locations, such as refuge floors, should be in a place that can be occupied by large number of evacuees and be linked to exit stairs (Weismantle et al. (2007)).

2.2. Features that affecting human behaviors

There are many features, such as emergency environment, number of waiting evacuees, familiarity, education and training, and floor level, which may influence human behaviors during elevator evacuation. Evacuees' psychological status is an important issue which will influence their behaviors (Kobes, et al. (2010)). Such status will be affected by the evacuation environment, and harmless smoke is an effective and safe way to enhance their pressures in experiments or drills. The limited space in cars and overload protection may lead to the failure of evacuation elevators when the number of waiting evacuees is large (Harding et al. (2010)). As a result, the relationship of number of waiting evacuees and the capacity of elevators is important. It is found that people tend to use the exit which they are familiar with (Sime (1983, 1985)), and the exit is usually the one they use in normal conditions (Ozel (2001)). To most people on upper floors in a high-rise building, they usually use elevators to transfer between floors. Based on these studies, evacuees' familiar exits are supposed to be elevators. However, the signs of warning against the use of elevators in the events of fire are posted in most of buildings around the world (Zmud (2007)). People are educated and trained not use elevators during evacuation, and this traditional point of view is required to be changed according to the long evacuation time in high-rises. During evacuation, people on upper floors are more likely to choose evacuation elevators than people on lower floors. Evacuees may get tired after travelling a long distance in stairs (Proulx (2004)), and they will intend to use elevators when they are fatigue (So, et al. (2003)). As a result, the floor level is another feature which may influence evacuees' behaviors. As we want to study evacuees' behaviors when they use elevators, two of these features will be tested: emergency environment and number of waiting evacuees (MacLennan et al. (2008)).

3. Experiments

The experiments were held in May 10 and 11, 2013. The experimental building layout is presented in 3.1. Before experiments, two tests were carried out in 3.2. In 3.3, the experiment plans and procedures are presented.

3.1. Building Layout

The experiments were carried out in Liuqing building in Tsinghua University, Beijing, China. It is an office building with 11 floors (the first floor is the lobby), and the initial evacuation place is on the 10th floor since many surveillance cameras are setup on this floor for research. There are two exit stairs and two elevators (in one elevator bank) which are shown in Fig. 1. People can wait for elevators in the elevator room, and they can also choose the stair in this room. Two elevators are all at the first floor before each experiment, and participants were told to wait for elevators on the tenth floor. One of these two elevators is shut down in the experiments. Elevator position and direction are shown on the board, and the elevator car, elevator room and stair structure are shown in Fig. 2. Generally, one car cannot afford 13 people according to our observation, although the capacity of each car is 13 people.

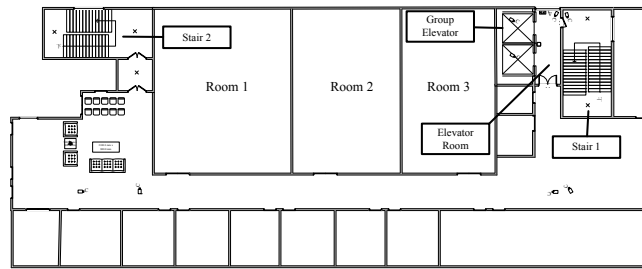


Fig. 1. building layout.



Fig. 2. car, elevator lobby and stair structure.

3.2. Tests before experiments

Before our experiments, two tests are held on the 10th floor. The graduate students in our lab took part in these tests, and 11 people and 12 people took part in test 1 and test 2, respectively. To test the experiment plan, participants were told to evacuate by elevators. If they cannot enter in the elevator or the car is overload, they should use the stair instead. All of them stayed in Room 1 at the beginning of the test, and they went out to the elevator lobby when the alarm sounded. In test 1, all the participants entered in the car and the time to open and close the door of the elevator (TOC) is 9.2s which is shown in Table 1. Different from test 1, the TOC of entering in is 19.4s in test 2, and the difference is more than 10s. The reason is overcrowding in test 2 (a snapshot is shown in Fig. 3(a)), one person came out of the car because the car is overload (shown in Fig. 3(b)). When the car was overload, one participant tried to enter in the car again after he went out, and this behavior delayed the TOC. In the two tests, TOC of going out of the car are nearly the same (around 9s).



Fig. 3. snapshots of tests.

Table 1. An example of a table.

Test	Number of waiting evacuees	Number of evacuees entered in	TOC of entering in (s)	TOC of getting out (s)	Overload
1	11	11	9.2	8.9	No
2	12	10	19.4	9.0	Yes

3.3. Experiment Procedure

Thirty participants were divided into two groups averagely, and each group took part in one group of experiments. They are all under graduate students in Tsinghua University, and their age range is 18-25. Before the experiments, they were told elevators were safe in our experiments, and they should use elevators as their first choice. In each experiment, if one participant cannot enter in the elevator at the first time, he/she should use the stair to go down to the lobby as “punishment”. As a result, participants would compete with each other and their motivations of evacuation would be enhanced. When evacuees arrived at the first floor, they were told to use elevators to go back to the 10th floor. Then the human behaviors of using elevators in normal conditions can be collected, and we can compare human behaviors in emergency conditions with those in normal conditions.

To test how smoke and number of waiting evacuees influence evacuees' behaviors, each group of experiments contains 16 sub-experiments based on different scenarios. The scenarios are shown in Table 2. As the capacity of the elevator is 13 persons and the number of evacuees in each group is 15, ten and fifteen were picked up as the number of waiting evacuees in our experiments. As there are two features to be tested, we have four scenarios in each group of experiments.

Table 2. Scenarios of experiments.

Scenario	Number of evacuees	Smoke	Scenario	Number of evacuees	Smoke
1	10	No	9	10	Yes
2	15	No	10	15	Yes
3	10	No	11	10	Yes
4	15	No	12	15	Yes
5	10	No	13	10	Yes
6	15	No	14	15	Yes
7	10	No	15	10	Yes
8	15	No	16	15	Yes

4. Results and Discussion

The results of our experiments are shown in sub-section 4.1. As we find that the shape of queuing determines the time to open and close the door of elevator, relevant research will be presented in sub-section 4.2. Several interesting phenomena are observed in our experiments, and they will be shown in sub-section 4.3.

4.1. Results of experiments

As mentioned in Section 3, we have four emergency scenarios and two normal scenarios which are shown in Table 3. In normal scenarios, people will take elevators to go up to the 10th floor, and there should not be smoke in the environment. Each of the two groups takes part in the experiments which are shown in Table 3. The times to open and close door of elevators of two groups are similar based on different scenarios, so the results of the two groups are analysed together based on scenarios. The results are shown in Fig. 4. The average TOC of the scenario with 15 participants is 15.44s, and the average TOC of the scenario with 10 participants is 12.06s. The maximum value of TOC is up to 44.72s, which happened in scenario with smoke and 15 participants. In this time of

experiment, people tried many times to re-enter the elevator. This value is too large to put into the box-figure, so it is not included in Fig. 4. As a result, the number of waiting evacuees will influence evacuees' behaviors according to the TOC, especially when the number of waiting evacuees is larger than the capacity of elevators. If the number of waiting evacuees become larger, there should be enough waiting area for them in case of they become anxiety.

Table 3. Four scenarios of the experiments.

	Number of evacuees	Smoke
1	10	No
2	15	No
3	10	Yes
4	15	Yes

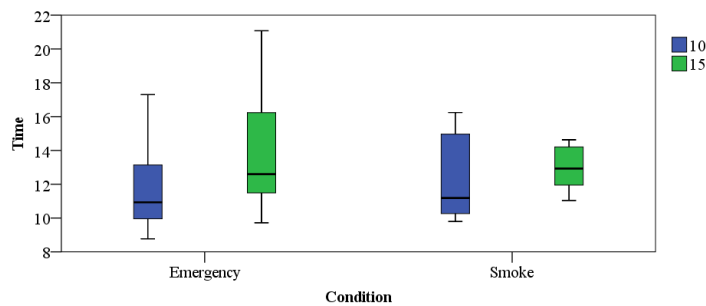


Fig. 4. analysis of experiment results.

When the numbers of waiting evacuees are the same, the smoke cannot influence evacuees' behaviors too much according to the average TOC. Even in the same scenario, the times to open and close the door of elevator are different from each other. That is to say, there are uncertainties in elevator evacuation.

In normal conditions, the average TOC is 12.85s which is larger than the average TOC of scenarios with 10 participants because people in normal conditions are not in a hurry. But the average TOC in normal conditions is smaller than that of scenarios with 15 participants. As mentioned above, only number of waiting evacuees will influence evacuees' behaviors, and the distributions of TOC with 10 participants and 15 participants are supposed to follow Normal Distribution. We use Matlab 7.8.0 to analyse the TOC based on frequency, and the results of scenario with 10 people and 15 people are shown in Fig. 5(a) and Fig. 5(b), respectively. The distributions can be used to simulate the elevator dynamics.

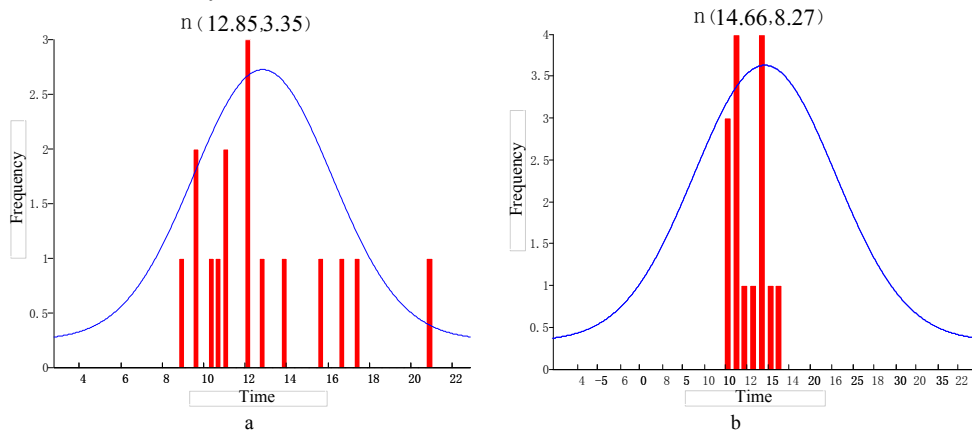


Fig. 5. (a) distribution of TOC with 10 people; (b) distribution of TOC with 15 people.

4.2. Enter-in Time and Shapes of Queuing

The enter-in time is different from TOC, and it is the time of all the participants need to cross the door of elevators. The average enter-in time of 10 participants is 9.56s, and the average enter-in time of 15 participants is 6.00s although the average TOC is 15.44s. It is interesting that the group with more people moved faster than the group with less people, and the reason is competition. When the number of waiting evacuees is 10, participants can estimate that all of them can enter-in the elevator, and they were not in a hurry. However, when the number is 15, all of them wanted to enter in the elevator as soon as possible since they knew the car may not afford all of them. This phenomenon indicates that competition is a very good way to enhance participants' motivation. Compared with the enter-in time, time to close the door of elevator occupies the most of TOC, and the comparison of TOC and enter-in time is shown in Fig. 6.

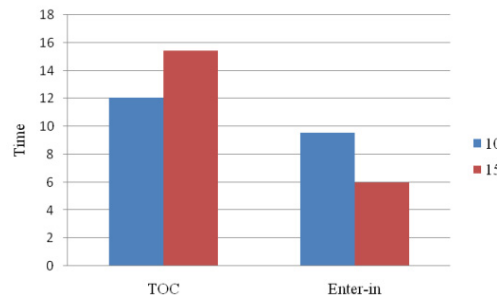


Fig. 6. analysis of experiment results.

There are two shapes of queuing in our experiments: line (Fig. 7(a)) and arc (Fig. (b)). The average enter-in time of line-shape is 6.41s and the average enter-in time of arc-shape is 5.31s. Participants with the shape of arc moved faster than those with the shape of line. When people try to crowd through a door, they will push each other, and the key which determines the pedestrian flow rate is the width of the door (Fruin (1971)). In our experiments, the width of the door of the elevator is 1m (the twice width of people's shoulder) which is a good width for pedestrians coming through. If the width of the door is similar to the width of people's shoulder, the pedestrian flow rate will reduce. This phenomenon indicates that the design of the door of elevator is very important.



Fig. 7. Shapes of queuing.

4.3. Phenomena

Several phenomena were observed in these experiments. When participants tried to enter in the elevator, they pushed each other. Especially for the scenarios with 15 participants, participants pushed even harder since they knew not all of them can use the elevator to evacuate. In the scenarios with 15 people, some participants at the back

hesitate whether they will wait for the elevator since the car may not afford all of them. Evacuees got out of the car one by one when the car is overload. When evacuees heard the alarm of overload, they did not know how many of them should get out of the car. They got out of the car one by one (except the ones with social bonds) until the alarm stopped. Some participants tried to enter the car once or several times after they got out. Such type of behavior delays the elevator loading time a lot. Although all the participants were told to use the elevator, there was still one person preferred to use the stair every time. He did not believe the elevator was safe during evacuation according to after-experiment interview. It is interesting that there are two persons who helped each in the experiments. After the experiments, we found out they are boyfriend and girlfriend. The man tried to push the woman in the car when the elevator door opened, and none of them wanted to get out of the car when the car is overload.

5. Conclusion

Experiments are carried out to study evacuees' behaviors of using elevators and two features are tested in the experiments. According to the results of experiments, evacuees' behaviors will not be influenced by smoke, but the number of waiting evacuees may influence their behaviors. The average TOC of the scenario with 15 participants is 15.44s, and the average TOC of the scenario with 10 participants is 12.06s. The maximum value of TOC is up to 44.72s, which happened in scenario with smoke and 15 participants. Different from the TOC, the enter-in time of 15 participants is less than that of 10 participants because of competition. There are two types of queuing (line and arc) which will influence the pedestrian flow rate of passing the door of the elevator. Several suggestions are given according to the analysis of the results of the experiments: width of doors and the design of elevator lobbies. The basic data of our experiments can be used to calibrate and validate elevator evacuation simulations.

In our future work, more features should be tested based on experiments, such as social influence (Nilsson, et al. 2009) or social bond, floor level, and guidance.

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